# CHROMA

*A human-centric AR application connecting color, space and users*

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**Abstract.** In the last few years, digital innovations such as AR, VR and sensing technologies have had a great impact in the sector of cultural heritage, offering new immersive standardized experiences to their visitors. Following this observation, this paper seeks to bring into light the theoretical background and research methodology of 'Chroma', a project that lies at the intersection of theories and empirical observations related to color, architecture, human - centric AR and human behaviour in a monument in Chania, Greece. Based on the hypothesis that color has the ability to alter spatial experience, and that different sound frequencies can intensify this experience, the paper aims at testing AR as a possible technology to study different sensual experiences in the monument, measure them and categorize them according to their emotional and cognitive impact. Thus, it builds on a methodology of work where a vast number of different colors and their combinations integrated in an AR app enables users to generate data at a conscious and subconscious level on a suggested site and becomes ground for further exploration.

**Keywords.** mobile AR, human-centric, color interaction, spatial perception

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Chroma: an AR Experimental Application on Color, Space and User Experience

## 1. Introduction

Color has been a science for several hundred years. Newton's discovery that light produces color put an end to much speculation surrounding the nature around it and encouraged objective, scientific study. Albers developed an "experimental method for studying and teaching color", a method based on the idea that only by observing color in the field of tension of the environment can one begin to understand the nature of color. "In visual perception a color is almost never seen as it really is - as it physically is. This fact makes color the most relative medium in art. To use color effectively it is necessary to recognise that color deceives continually. To this end, the beginning is not a study of color systems." (Albers, 2013). Colors affect our bodily functions, our mind and our emotions through the energy generated by light. Studies have shown the positive effects of colors in terms of brain development, creativity, productivity, and learning. When color is transmitted from the eye to the brain, the brain releases a hormone that affects emotions, mental clarity, and energy levels. The negative and positive psychological effects of colors can be observed in people depending on the combination in which they are used.

Moreover, sounds affect us physiologically in a very powerful way. Since hearing is our primary sense of warning, a sudden sound will set a process in motion. The effects of sound on users are physiological, psychological, cognitive, and behavioural (Treasure, 2017). Sound transmits well in water. Human bodies are 70% water, thus becoming good conductors of sound. Sound is related to feelings and can cause stress and negativity. As such, sound can be an attractor or a repeller of an experience acting as an enabler of emotions and sounds.

The emergence of new immersive technologies has promoted the design and development of new experiences that enhance the spatial perception of cultural heritage monuments. Specifically, AR technologies enable the juxtaposition of new content on the physical space through a digital layer that contains computer-generated content. Furthermore, AR can become the means to better understand and evaluate an architectural idea for the purpose of intervening or redesigning-reusing an existing space, improving current practices of visualizing the design and conceptual process (Dania et al, 2021). For this reason, the specific project aims at uniting the above mentioned under a research experiment where each factor is studied differently and autonomously and altogether may open up the discussion for human behavior and interaction.

## 2. Methodology

The experiment of this case study tool place at the old port of Chania, inside the monument of Yali Tzamisi in Chania. This monument is chosen because of its location as a pivotal point in Chania, Crete so that it can be easily visited, making the experiment resemble the idea of a pop-up event. In addition, it is a well-known building, with its own history, which constitutes an experience evoking personalized emotions. A place experienced by diverse groups of visitors, causing them different reactions is suitable for investigating the effect of spatial changes on human reactions. Recognizing its visitability, its materiality, its architecture, it is an ideal location for public experimental

data collection based on the design of the present AR project unfolded in the previous section.

For this paper the authors followed a methodology of two phases. The first phase included all the preliminary studies that were necessary for the preparation of the mission, and it consists of the following steps: a) Empirical observations about color, space and human behaviour at the selected monument without the use of technology, b) Literature review on the history, impact, and theories of color in the interior spaces. A number of scholars, books and publications are studied so as to better comprehend the combination of color, psychology and human experience in space. From the study, the concepts of Meerwein, Rodeck, Mahnke (2007) on people's different reactions to color and established universal color concepts that meet the expectations of different user groups as well as of Adams, 2017, in the history and cultural connections of each colors, and of Best (2012) on the impact of color on localities and on the issues surrounding the use of color, from the basic principles of what color is to its important applications in a variety of industries, were highlighted as guiding throughout the experiment process, and c) 3D scanning and modelling of the selected monument and d) Designing an AR app in Unity in two parts. From each step, a number of elements were defined and classified such as the palette of colors that stands as the background tools for the AR app, and the construction of the interactive parts of the AR named, the space - color - and sound.

The second phase refers to an experiment organized by the research team inside the selected monument, during June 2022 for educational reasons to support the diploma thesis of one of the authors on how to use color in an AR app as to offer an alternative experience of the monument. On this occasion, participants used the AR app, and among a sample of 32 people, 13 users wore the neurowave sensor as agents to measure brain activity during the experiment, while all of them replied to pre-defined questionnaires related to their new experience of the space. The group was formed by 19 female and 13 male participants, including: a) students from the Technical University of Crete, School of Architecture, external participants, and other visitors. Some participants were related to architectural science, others from different geographic areas, which reveals the interest and curiosity the program is raising. In the end, the results of the above were further elaborated statistically and assisted in drawing the conclusions of the specific exercise.

## 3. The research project

### 3.1 COLORS AND SOUNDS AS A SPACE MODIFIER

The theoretical background of this research is based on empirical observations on how we perceive colors, shapes and emotions and what connections might exist between the different human brain parts. It is known that the limbic system is the part of the brain responsible for behavior and emotional responses. For example, the limbic system consists of the hypothalamus, which not only controls emotional reactions but is also involved in regulating body temperature. This fact also explains why red and blue colors can also affect our body temperature (Ho et al., 2014).

Sound also promotes certain states of consciousness. According to Jefferies and Lepp (2012), ultra-gamma frequencies are suitable for extremely intense information processing and concentration. Based on the fact that frequencies from the Ultra-Gamma can be associated with certain emotions and state of consciousness (Jefferies, Lepp, 2012), the team assigned frequencies to colors to render the whole experience more tangible for the user (Table 1). Building on previous research (Karaspiliou, 2022), each color was matched with an ultra-gamma frequency that acts as the intensifier of the experience. Specifically, the frequency of 100 Hz is used as a neutral agent, thus being assigned to the white color, higher frequencies are assigned to yellow and blue rooms, while lower frequencies correspond to red and black rooms. The association of colors, frequencies and sentimental status shapes the hypothesis and becomes the ground for further exploration.

| Colors | | | | | |
|---|---|---|---|---|---|
| Rooms | Red Room | Yellow Room | Blue Room | Black Room | White room |
| Description | Anger is a reaction to threats or stressors in the environment. Anger emanates from the amygdala, which stimulates the hypothalamus, just like the response to fear. | Happiness refers to a general state of well-being or contentment. Imaging studies suggest that the happiness response originates in part from the limbic cortex. | Relaxation means that the body and mind are free of tension and anxiety. Relaxation is a form of mild ecstasy that emanates from the frontal lobe of the brain, where the posterior cortex sends signals to the frontal cortex via a mild sedative. | Like anger, it helps us respond appropriately to threatening situations that could harm us. This reaction is triggered by stimulation of the amygdala, followed by the hypothalamus. This process produces hormones such as adrenaline and cortisol. When these hormones enter the bloodstream, you may notice some physical changes, such as an increase in heart rate, breathing rate, blood sugar and sweating. | Neutral is a state in which all our emotions are on the same wavelength. |
| Emotions/Status | Anger, energy, increase pulse | Happiness, energy, increase pulse | Relaxation | Fear | Neutrality |
| Sound Frequency/ Hz | 150 Hz | 540 Hz | 432 Hz | 100 Hz | 250 Hz |

Table 1: Theory around colors, emotions, and frequencies (Karaspiliou, 2022)

## 3.2 COLORS AND SOUNDS AS A SPACE MODIFIER

Yali Tzamisi is the only surviving mosque in the city of Chania, that dates to the second half of the 17th century and is a listed archaeological site of Crete. Located at the front of the Venetian Port of Chania, Yali Tzamisi is a cubic building, covered by a large hemispherical dome supported by four elaborate stone arches. On its western and northern sides, it is surrounded by a portico covered by six small domes. The northern portico is used as an information point for the city visitors. For a few years, the monument hosted the Archaeological Museum of Chania, while nowadays, it serves as a venue for exhibitions and venues.

Initially, the experience was designed considering the architectural spatiality of the Mosque. Yali Tzamisi has two main entrances, a north and a western one, both having a sea view. To ensure that all users would follow a predesigned path, the western part was considered as the main entrance, while the northern one was made inaccessible for users. During the second step, the Mosque was 3D scanned and set up into the Unity platform as a point cloud model (Figure1 & 2). The third step included the design and implementation of the immersive part of the application. The western part of the monument was virtually divided into five different rooms, each one ‘painted’ in one of the basic colors: red, yellow, blue, black, and white (Figure 2). Based on the hypothesis, the experience was enhanced by the frequencies enabled when users entered each virtual color room.

Figure 1. Vuforia scan.

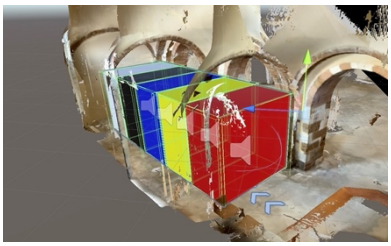

Figure 2. Colored boxes in Unity

At the fourth step, the building was used as a "canvas" with specific predefined color palettes available to the user-visitor. Six predefined sets of colors were empirically created and grouped into color palettes: 1. Van Gogh, 2. The Mediterranean, Islam, Baroque, Bauhaus, Impresionism. The color palettes were created through the collection of a vast number of artifacts related to the specific Art movement or environment combined with the empirical observation on which colors repeatedly appear in these artifacts. Namely, at this stage, the user selects the desired colors and the application projects them on the real walls through a digital layer that implements the AR functionality. At this point, users could move to the center of the main area, either seated or standing, and through the use of an iPad, they could follow instructions on the three consecutive experiments. Through this exploration, the application intended to educate users on three fields: 1) how colors affect space, 2) how colors affect each other and 3) how geometry, space and colors are interrelated. As such, the palettes acted as a connecting tissue of the three experiments. The first experiment reflected how the spatial experience of a certain color is transformed when this color is juxtaposed on different colors (Figure 3 & 4).

Figure 3. Second experiment.

Figure 4. Second experiment.

Following the UI instructions, users could first choose a palette, then pick three colors and explore how the first color was perceived when juxtaposed to different colored canvases. Along the same lines, at the second experiment, users would pick four different colors and see the different ways of color combination within the projected AR layer on the interior of the Mosque (Figure 5).



Figure 5 (left). Color Projection on the interior of the Mosque. Figure 6 (right). Reflective stained-glass dome inspired by "Nuit de Noël", Matisse, 1958.

Each color combination would be projected for fifteen seconds until the end of the experiment. Regarding the last part of the experiment, the research team tried to alter the spatial experience by virtually reconstructing the solid structure of the dome of the building, digitally replacing it with its transparent clone with reflective stained glass inspired by "Nuit de Noël", Matisse, 1958 (Figure 6). The goal was to simulate the sun, its light and its movement during the day by reconstructing the interior of the building showing how the colors and light could change the spatial experience.

### 3.3 AR TECHNOLOGY & USER INTERFACE

The digital tool in use, was created with the real-time development platform Unity and Vuforia SDK and utilizes Augmented Reality (AR) technology. The application is aimed at mobile devices and the system includes two subsystems / functions, the stereoscopic mode, and the full screen mode. The digital content being used to augment the selected place is color enhanced with sound as described in the previous section.

The combination of the place, technology and content sets the following experience: Initially, in the first stages/ virtual rooms, the user is required to experience full immersion, while tactile interaction with the application is not necessary. Thus, at this stage of the experiment, the subsystem/sublevel of the application's stereoscopic function is implemented. Specifically, the user places the mobile phone in special AR glasses and begins the predetermined passing through the fully colored rooms augmented with the predetermined audio background, following the sequence: red room, blue room, yellow room, black room, and finally white room (Figure 7). The second stage of the experiment requires user interaction with the application's interface and personalized dynamic management of the experiment's content (color selection, viewing angle, target surface). At this stage, the user has the mobile device in her/his hands and the application runs in full screen mode. Therefore, with the pre-designed color palettes at her/his disposal, the user selects colors and digitally transforms the space in real time into an experimentally personalized canvas.

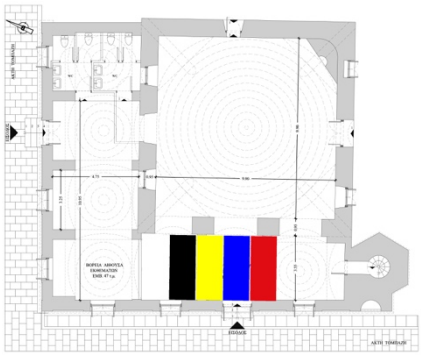

Figure 7. Floorplan of the existing building with the location of the colored boxes.

The overall process aims to collect information based on the user experience, leading to a pool of data and, through its systematic analysis, providing answers regarding the original research question. Data is acquired in two ways: questionnaires for the end users and through a special headset with biosensors (MindWave Mobile 2 Headset) that record the electrical activity of the user's brain during the experiment.

## 4. Data Collection & Analysis

The first set of data collection was implemented through questionnaires that were answered by 32 users in total, 19 men and 13 women. The first set of questions asked users to describe the feeling that can be most related to the experience of each room. At this point, it seemed that all rooms except for the white one demonstrated a clear connection with a specific feeling or similar feelings. 78% of the users related the red room with stress, while the yellow room was primarily associated with joy (41%) and secondarily with calmness (25%). The blue room was associated with calmness by 63% of the users while the black room was linked to fear by 44% of the users and sadness by 19%. The white room had a diverse range of answers. Specifically, 34% associated the experience with stress, 25% with calmness, and 22% thought it was neutral (Figure 8).

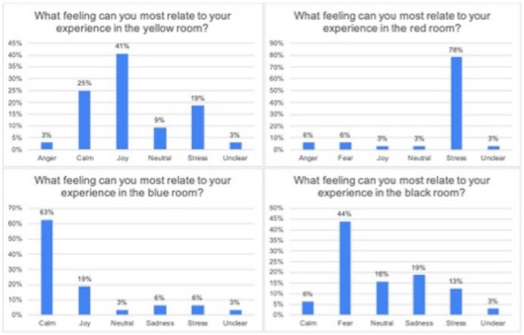


Figure 8. Data resulting from the questionnaires

The second set of questions intended to validate the findings of the first part through a different set of questions. For example, the question "which room scared you" validated that fear is connected to black, as 66% of the users chose the black virtual room. The question "which room gave you positive feelings?" confirmed that blue (38%) and yellow (38%) are associated with positive feelings, while red (3%) and black (3%) are linked to such feelings. As a result, blue and yellow are the colors of the rooms in which guests had the most frequent positive emotions, black and red for the least frequent positive emotions (white was found somewhere in the middle). Again, the darker the rooms, the less often for positive emotions. Black, red, yellow, white is, in (descending) order, the colors of the rooms that cause negative effects from most to least often (the darker the color, the more often it causes negative emotions).

Statistically, by checking the null hypothesis that black rooms do not generate more fear than other-colored rooms and do a one-sided two proportions z-test, this null hypothesis was rejected with a significance level of 0.05 as we have a p-value of 0.045. As a result, the fact that black rooms generate more fear that the other colored rooms combined was proven. Parallel to the data collection through the questionnaires, when visiting the virtual color rooms (third part of the research process), users were asked to wear a headset that recorded their brain activity and depicted values from 0 to 100 for two parameters: attention and meditation (Figure 9). The users' brain activity was recorded and juxtaposed on the screen recording of the mobile AR application (Figure 10&11).

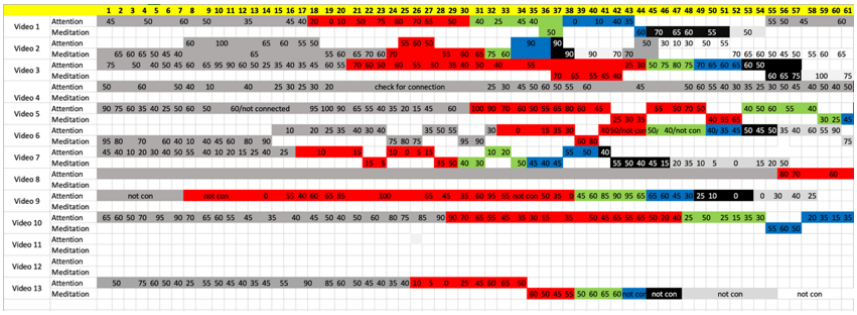


Figure 9. Data extracted through the Headset - Attention / Meditation (axis X = time, axis Y = users), in addition to the amount of time the viewer stayed in each colored room (Red colored boxes is red colored room, blue-colored boxes is blue room etc.)

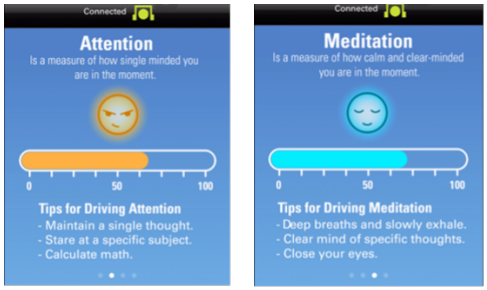


Figure 10&11. Headset Interface – Meditation/Attention

The research team gathered two types of data, based on the AR application: the conscious data extracted through the questionnaires, and the subconscious data, extracted through the headset that recorded the meditation and attention factors. The conscious data clearly showed the correlation of colors with certain feelings, while, according to the subconscious data (based on ANOVA) we could not find a statistically significant difference of the mean values of the two variables (meditation – attention) based on the visited room.

## 5. Discussion and Further Research

Overall, the current research detected differential evidence on the ways that colors can be associated with brain activity. On the one hand, the data extracted by the questionnaires validated the hypothesis and revealed a clear correlation of color with a specific feeling. On the other hand, the ANOVA of on the measured brain activity demonstrated that the designed immersive experience did not trigger a substantial difference at the average brain activity of each room. The negligible difference of compared meditation and attention averages in each room produces vague results on the correlation of color, sound and meditation or attention levels through biometric data. This finding probably flows from the following facts: a) the experience was designed as a continuous transition from one virtual room to the other, thus encouraging users to stay in every virtual room only for a few seconds, b) the biosensor used has a limited sensitivity and c) the human brain is not affected by different kinds of color in the case that the AR layer contains color embedded in space and not as a form of a specific stimuli. As such, for further exploration and research, the above limitations need to be tested. Moreover, combining the same colors with different frequencies is another field that could be further tested and compared to the acquired data.

In this case, the combination of color and sound are used as a flexible means of shaping space that can give meaning, context, and identity, support architectural form or act subversively against it. In this sense, ‘Chroma’ is intended to be a pop-up installation, so it can be used in any type of building, indoors or outdoors, in any location, etc. At this strand of the research, the team articulated the initial hypothesis based on empirical findings on the influence of color and sound to the spatial experience. This hypothesis served as the ground for the design and development of the AR application. Through the process of extracting user-generated data, the team was able to collect both conscious and subconscious cognitive data associated with the sensual perception of space. This methodology can be further elaborated to demonstrate the correlation of user-generated data with color, sound, and space, opening up new horizons for the typological classification of user experience assessment based on color and sound.

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